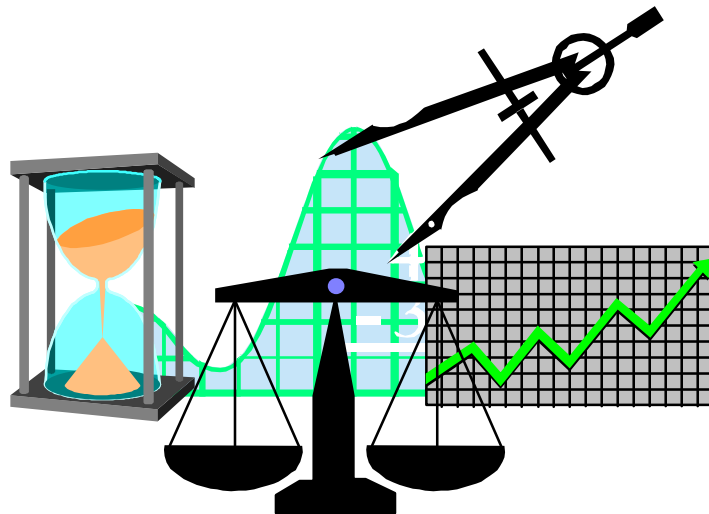




# ***Systems Engineering Measurement Primer***



A Basic Introduction to Systems Engineering Measurement  
Concepts and Use

Version 1.0

March 1998

This document was prepared by the Measurement Working Group (MWG) of the International Council on Systems Engineering (INCOSE). It was approved as an INCOSE Technical Paper by the INCOSE Technical Board.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>MAR 1998</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-1998 to 00-00-1998</b>	
4. TITLE AND SUBTITLE <b>Systems Engineering Measurement Primer</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>International Council on Systems Engineering, Measurement Working Group, 2033 Sixth Avenue, Suite 804, Seattle, WA, 98121</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>40</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

# ***Systems Engineering Measurement Primer***

This document was prepared by the Measurement Working Group of the International Council on Systems Engineering. The authors who made significant contribution to the generation of this Primer are (in alphabetical order):

Patrick Antony	Boeing
Jennifer Dunn	Tellabs Operations, Inc.
Dr. William Farr	Naval Surface Warfare Center
Dr. Donna Rhodes	Lockheed Martin Federal Systems
Garry Roedler	Lockheed Martin Management & Data Systems
Cathy Tilton	The National Registry, Inc.
E. Richard Widmann	Raytheon Systems Company

Copyright 1998 by INCOSE: This document is the result of a project by the members of the International Council On Systems Engineering (INCOSE) Measurement Working Group (MWG). Permission to reproduce this product and to prepare derivative products from it is granted royalty-free provided this copyright notice is included with all reproductions and derivative products.

This document was prepared by the Measurement Working Group (MWG) of the International Council on Systems Engineering (INCOSE). It was approved as an INCOSE Technical Paper by the INCOSE Technical Board.

## Revision History

Version	Date	Comments/Description
Version 1.0	03/03/98	Approved by INCOSE Technical Board as an INCOSE Technical Paper

# **Preface**

## **Acknowledgements**

The completion of this document also required the review and comment of many people from the Measurement Working Group, Measurement Technical Committee and other groups in INCOSE. The effort spent reviewing, commenting and resolving comments to this document by each of the following individuals was greatly appreciated:

Dennis Brink  
Donald Gantzer  
Mark Kassner  
Gerry Ourada  
Norman Sanford

INCOSE technical documents are developed within the working groups of INCOSE. Members of the working groups serve voluntarily and without compensation. The documents developed within INCOSE represent a consensus of the broad expertise on the subject within INCOSE. The development of some INCOSE products include expertise from outside of INCOSE through collaborative participation of other technical groups.

## **Endorsement of the SE Measurement Primer**

The MWG is one three working groups that comprise the Measurement Technical Committee of the Technical Board of INCOSE. At the Winter Workshop in January 1998, the Systems Engineering Measurement Primer was presented to the INCOSE Technical Board for endorsement to publish it as an INCOSE Technical Paper (a designation given to all approved products of the INCOSE Technical Board to include handbooks, models, reports, etc.). This approval was granted on March 3, 1998.

## **Comments**

Comments for revision of INCOSE technical reports are welcome from any interested party, regardless of membership affiliation with INCOSE. Suggestions for change in documents should be in the form of a proposed change of text, together with appropriate supporting rationale. Comments on technical reports and requests for interpretations should be addressed to:

**INCOSE Central Office**  
2033 Sixth Avenue #804  
Seattle, WA 98121

### **Additional Copies / General Information**

Copies of the Systems Engineering Measurement Primer, as well as any other INCOSE document can be obtained from the INCOSE Central Office. General information on INCOSE, the Measurement Working Group, any other INCOSE working group, or membership may also be obtained from the INCOSE Central Office at:

International Council on Systems Engineering  
2033 Sixth Avenue, Suite 804  
Seattle, WA 98121  
E-mail: [incose@halcyon.com](mailto:incose@halcyon.com)  
Telephone: (800) 366-1164 (in Seattle, use 206-441-1164)  
Facsimile: (206) 441-8262  
Web Site: <http://www.incose.org>

### **INCOSE Technical Board, Measurement Technical Committee and Measurement Working Group Information**

Information regarding the INCOSE Technical Board and INCOSE technical products, policies, goals, activities and strategic planning can be obtained from:

Chair, INCOSE Technical Board  
(See INCOSE web site for current Technical Board contact information.)

Information on the INCOSE Measurement Technical Committee and its products, strategic planning, coordination of INCOSE measurement products, and activities of the three working groups within the Measurement Technical Committee, can be obtained from:

Chair, INCOSE Measurement Technical Committee  
(See INCOSE web site for current Measurement Technical Committee contact information.)

Information regarding the Systems Engineering Measurement Primer, the Measurement Working Group (MWG), other MWG products, development plans for new products, MWG strategic plans, MWG activities, and the collaborative project for Practical Systems Measurement can be obtained from:

Chair, INCOSE Measurement Working Group  
(See INCOSE web site for current Measurement Working Group contact information.)

# Table of Contents

REVISION HISTORY .....	III
PREFACE .....	IV
1. INTRODUCTION .....	1
1.1 ORGANIZATION AND OBJECTIVES OF THE PRIMER .....	1
1.2 SCOPE .....	1
2. DEFINITIONS AND COMMONLY USED TERMS .....	3
3. MEASUREMENT PROCESS AND SUPPORTING INFRASTRUCTURE .....	7
3.1 THE MEASUREMENT PROCESS .....	7
3.1.1 <i>Selection and Specification of Measures / Indicators</i> .....	8
3.1.2 <i>Data Collection Method</i> .....	12
3.1.3 <i>Calculation Method: Getting from Measures to Indicators</i> .....	12
3.1.4 <i>Analysis of the Measures or Indicators: Measurement Interpretation</i> .....	13
3.1.5 <i>Reporting and Using the Results</i> .....	14
3.2 MEASUREMENT PROGRAM SUPPORTING INFRASTRUCTURE .....	14
3.2.1 <i>Management Commitment</i> .....	15
3.2.2 <i>Measurement Plan</i> .....	15
3.2.3 <i>Resources</i> .....	16
3.2.4 <i>Training</i> .....	16
3.2.5 <i>Tools</i> .....	16
3.2.6 <i>Measurement Data Repository</i> .....	17
4. PURPOSES OF MEASUREMENT .....	18
4.1 DEFINING AND COMMUNICATING THE PURPOSE OF MEASURES .....	18
4.1.1 <i>Characterization: Gain Understanding of Products and Processes</i> .....	19
4.1.2 <i>Improvement: Identifying and Evaluating Process and Product Improvement Opportunities</i> .....	20
4.1.3 <i>Prediction: Facilitating Projections and Planning</i> .....	21
4.1.4 <i>Evaluation: Providing Feedback and Status</i> .....	21
5. APPLICATION GUIDANCE AND LESSONS LEARNED .....	22
5.1 CONTRASTING CORRECT AND INCORRECT USES OF MEASUREMENT .....	22
5.2 TIPS AND RULES OF THUMB .....	23
5.3 HUMAN FACTORS .....	25
6. LIST OF REFERENCES .....	26
6.1 MEASUREMENT REFERENCES .....	26
6.2 SELECTION OR CREATION OF A METRIC .....	26
6.3 STARTING A MEASUREMENT PROGRAM .....	27
6.4 IMPROVING AN EXISTING MEASURE .....	28
6.5 INTRODUCTION TO STATISTICS, SPC, AND PROCESS IMPROVEMENT .....	28
7. EXAMPLE MEASURES .....	29
7.1 EXAMPLE <u>PROCESS MEASURE</u> : REVIEW RATE .....	29
7.2 EXAMPLE <u>PRODUCT METRIC</u> : DEFECT DENSITY .....	30
7.3 EXAMPLE <u>PROGRESS METRIC</u> : REQUIREMENTS STABILITY .....	31
8. FEEDBACK FORMS .....	33

# 1. Introduction

Welcome to the INCOSE Systems Engineering Measurement Primer. This primer is not intended to be a tool, a case study, or a guideline. It is a basic introduction to measurement for the beginning measurement practitioner in systems engineering. It is written from the perspective that the reader is not familiar with measurement jargon, does not know the general philosophies shared by many measurement practitioners, or has no experience selecting, specifying, and using measures. This Primer will provide the reader with the basic knowledge of measurement from which more specialized topics in measurement can be explored.

## 1.1 Organization and Objectives of the Primer

This document is organized to address two main goals. The first objective is to define the basic concepts behind measurement and measurement programs in such a way that they will be usable and readable by anyone regardless of their experience and background; these concepts are described in sections 2 and 3. The second objective is to provide the background knowledge needed to *prepare you to set up* a measurement program; sections 4 through 7 are designed to achieve this aim.

Section 8 is intended to provide feedback on the primer. Questions or comments should be submitted per the instructions in this section.

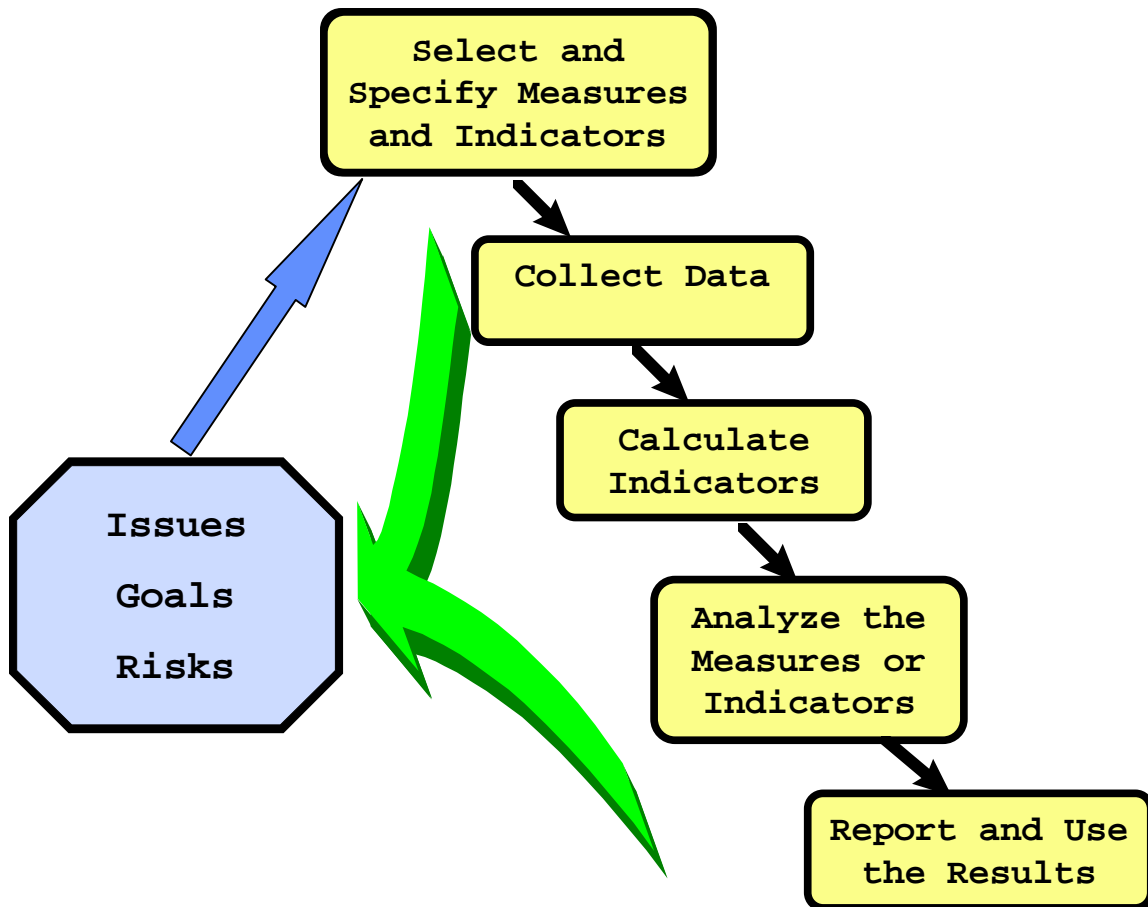
## 1.2 Scope

*What is included in the Primer:* The fundamental measurement concepts covered in this Primer include a glossary of the language common to all measurement practitioners, a description of the principles shared by most measurement programs and their users, and generic components of successful measurement programs. The principles included here are consistent with the INCOSE Metrics Guidebook for Integrated Systems and Product Development and the Joint Logistics Commanders (JLC) Practical Software Measurement (PSM) guidebook, which are among the leading guidebooks for systems and software measurement. The contents of this Primer also encompass a proven measurement process (see figure 1) and some guiding principles for those intending either to use measures or to set up a measurement program. This discussion provides guidance on how to effectively use measurement, avoid its misuse, select good measures, obtain the benefits from correct use of measurement, and find references to other resources that discuss more specialized topics in measurement.

*Boundary of the document:* This Primer is not a comprehensive guidebook; it does not define a step by step process on how to set up a measurement program. It is not directed toward any particular organization or individual, nor is it an identification of the all-purpose set of measures. Most importantly, this Primer does not guarantee the success of a measurement program or the project it is supporting.



Successful measurement programs are also dependent on the practitioners having a good understanding of statistical concepts before endeavoring to create a measurement program. Many of the terms and theories commonly used by measurement practitioners are derived from statistics. A few statistical concepts are mentioned or described briefly in this Primer for informational purposes only; however, this Primer will not provide the reader with any detailed explanations. It is possible to create a successful measurement program without having a solid statistical foundation, but it may make it more difficult.



**Figure 1: Measurement Process Diagram**

## 2. Definitions and Commonly Used Terms

The list below defines basic measurement terms used in this Primer.

<b>Causal Analysis</b>	A systematic method for identifying specific problem areas in work products, project progress, and processes, determining the causes of problem areas, and developing and implementing solutions to prevent the problem areas from occurring in the future.
<b>Control Chart</b>	A graphical method for evaluating whether a process is or is not in a state of statistical control (SPC). This chart analyzes a process attribute measure as a function of time for determining process performance status. The values plotted on a control chart are obtained from a sequence of individual measurements for any statistic.
<b>Control Limits</b>	<i>(Upper and Lower)</i> The upper and lower values of a process attribute between which nearly all sample points fall. These control limits form a tolerance band within which the performance of the process is considered to be statistically in-control. Control limits are often represented by lines on a control chart that are used to judge whether the process performance being measured is out-of-control. For example, an upper control limit would be a set value of a measure or indicator that represents a boundary inside which accepted values of the measure should lie. If the observed value(s) exceeded this set value, or upper control limit, the process/performance parameter being measured would be considered “out of control.”
<b>Data Element</b>	Data at the level it is collected and prior to any processing or analysis.
<b>Demonstrated Value</b>	The parameter value that is demonstrated or estimated through analysis and modeling or measured in a particular test. (Adapted from DSMC SEMG.)

<b>Indicator (Metric)</b>	<p>1) A measure or combination of measures that provides insight into an issue or concept. Indicators are often comparisons, such as planned versus actual measures, which are usually presented as graphs or tables. Indicators can describe the current situation (current indicators) or predict the future situation (leading indicators) with respect to an issue. (Adapted from PSM.)</p> <p>2) A mathematical composite of relevant, quantifiable, product, project progress or process attributes (measures) taken over time that communicate important information about quality, processes, technology, products, projects, and/or resources.</p>
<b>Issue</b>	A risk, constraint, objective, or concern, often associated with resources, progress, quality, or performance. Issues represent current or potential problem areas that should be monitored. (PSM)
<b>Linear Regression</b>	A straight line representing the estimated linear relationship between two variables.
<b>Measure</b>	The result of counting or otherwise quantifying an attribute of a process, project or product. Measures are numerical values assigned to attributes according to defined criteria. The raw data from which indicators are calculated. Some examples of these are size, cost, and defects. <i>(Synonymous with ‘measure’ is a <b>measurable</b>, a <b>data element</b>, or a <b>primitive</b>.)</i>
<b>Measurement</b>	The process of assigning numerical values to process, product, or project attributes according to defined criteria. This process can be based on estimation or direct measurement. Estimation results in planned or expected measures. Direct measurement results in actual measures.
<b>Measurement Analysis</b>	The use of measurement data to identify problems, assess problem impact, project outcomes, and evaluate alternatives related to identified issues. Examples of measurement analysis are estimation, feasibility analysis, and performance analysis. (Adapted from PSM.)
<b>Measurement Program</b>	An organizational initiative responsible for the planning, educating, and facilitation/execution of measurement for the purpose of process, product, and/or project control and improvement.

<b>Measurement Tool</b>	A device or software program that automates some process (data collection, measure or indicator calculation, graph plotting, etc.) within a measurement program.
<b>Normalization</b>	A technique that <i>meaningfully</i> compare or combine data from different processes, products or projects, or with different units of measurement. This often requires the definition and validation of conversion rules and/or models. For example, to compare the quality of work produced in two programs, it would be necessary to look at defect counts in relation to the amount or size of the work produced in the same units of measurement. (Adapted from PSM.)
<b>Planned Value (Target or Expected Value)</b>	The anticipated value of a parameter or measure at a given point in the development cycle. The anticipated value may be the result of historical measurement data, an empirical model, or an estimation tool. A plot of planned value versus time is known as the planned value profile. The range of acceptable values is called the tolerance band. (Adapted from DSMC SEMG.)
<b>Process Measure</b>	A measure of how well a given process or activity is working, which can provide insight into process stability and process improvement opportunities. Historical data from process measures also provides a basis for estimation of processes applied on similar projects. An example of this type of measure might be activity cycle time or rework factors.
<b>Product Measure</b>	A measure of the characteristics or quality of an end item. This end item could be anything from the shipped product to the system design specification document to a quantifiable measure of service performed or level-of-effort provided.
<b>Progress Measure</b>	This measure provides project or program status in terms of schedule and cost. It measures values or changes over time, generally against planned values. Most budget/cost and schedule measures are progress measures.
<b>Root Cause Analysis</b>	The process by which a single event that represents a fault in work products and processes is analyzed to determine the fundamental cause for the fault. Based on this understanding, a correction can be made to the product or process to resolve the fault.

**Statistical Process Control (SPC)**

(See Section 6.5 for references on this topic.)

1) The use of data and statistical analysis techniques (e.g., control charts) to analyze and measure variations in processes in order to determine whether:

- The process is out-of-control (if a problem exists) and the action required to correct the problem (i.e., sources of variability also called assignable causes)
- Improvement actions have been effective

2) SPC is a method for monitoring, controlling, and improving a process for the purpose of maintaining the performance of the process. (Software Productivity Consortium)

**Technical Performance Measure**

An attribute of a system that can be measured to determine how well a system is satisfying or meeting a technical requirement or goal. It provides an assessment of the product design by estimating the values of essential performance parameters of the design through engineering analyses and tests. TPMs are used to:

- Forecast the values to be achieved through the planned technical effort
- Measure differences between the achieved values and those allocated to the product by the systems engineering process
- Determine the impact of these differences on system effectiveness.

The purpose of a TPM is to:

- Provide visibility of actual versus planned performance
- Provide early detection or prediction of problems requiring management attention
- Support assessment of technical impact of proposed change alternatives.

(Adapted from DSMC SEMG.)

**Variance**

1) The difference between the planned value and the actual, demonstrated or current value of a measure or parameter.

2) A measure of the variability of a random variable, calculated as the standard deviation squared.

### 3. Measurement Process and Supporting Infrastructure

Measurement is much more than the data collected and the calculation of an indicator. Effective measurement requires planning of what will be measured, how the measurement will be performed, how the data will be analyzed, what reporting is needed, what actions will be taken for the results, and who is responsible for each of these activities. Thus, a measurement program is usually established that defines the measurement process for the organization and provides an infrastructure to support the measurement process activities.

The first task of the measurement program is to identify its purpose for measurement. Organizations usually perform measurement for one of the following reasons [SEI/MPM]:

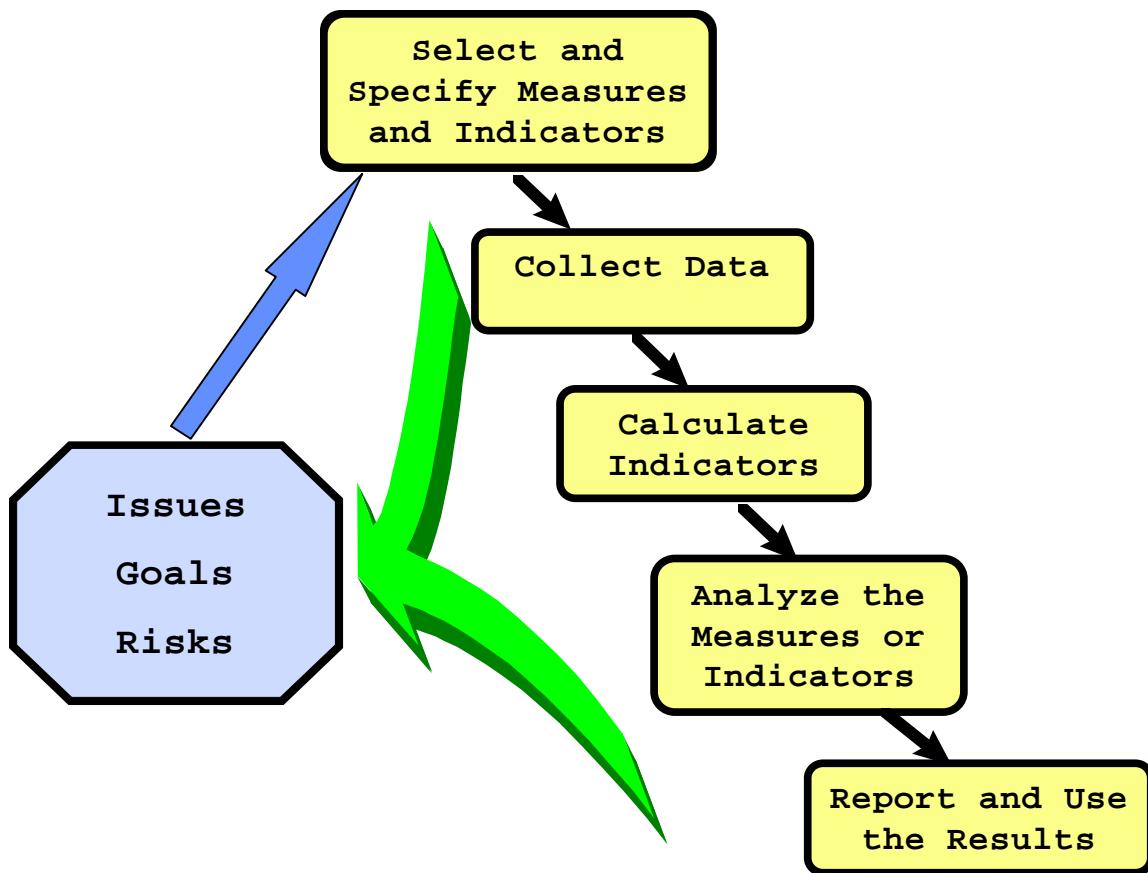
- Characterize or gain an understanding of their processes, project progress and/or products and establish baselines for future assessment of these
- Evaluate or determine project progress with respect to plans
- Predict resources, schedule and performance to support planning and trades
- Identify improvement opportunities for progress, processes and/or products, such as roadblocks to progress, root causes of problems in products, and inefficiencies in processes

These will be discussed in more depth later in this section.

Once the purpose for performing measurement has been established, it is essential to determine the measurement process that will be employed by the organization. Both the purpose and process for measurement needs to be communicated throughout the organization to all stakeholders. The definition of the process will help determine what needs to be included in the supporting infrastructure. This Primer will cover common process activities and practices used by many successful measurement programs and the typical components of the supporting infrastructure.

#### 3.1 The Measurement Process

Measurement needs to be viewed as a process for obtaining vital insight into the progress, products, and/or processes of the project or system being developed. This insight helps the decision maker to make more informed decisions, identifying deviations from plans earlier, thus allowing mid-course corrective actions when it is least expensive to make them. Measurement should not be viewed as a set of predefined measures that never change throughout the program. Instead, the measures used need to address the current issues at hand, which may change with time. The process includes the activities for selecting and specifying the measures, establishing a measurement plan, planning and executing the data collection and storage, analyzing the data, reporting the results, and most importantly, taking action. These fundamental activities are explained in this section. Figure 1 shows the process for measurement that is described in the paragraphs below.



**Figure 1: Measurement Process Diagram**

### **3.1.1 Selection and Specification of Measures / Indicators**



The measures that are selected are the key to successful measurement. Before any data is collected, the project management team and stakeholders perform measurement planning. This includes identifying and prioritizing the program issues, selecting and specifying appropriate measures, and integrating the measurement activities into the standard processes of those performing the work. During this planning activity, current and expected issues are reviewed to identify the relevant measures (quantitative data) that, when combined with other program data, will provide insight into those issues. The objective is to define the set of measures that provides the best indicators and insight for the least cost. Thus, measures that are based on existing data sources and/or measurement tasks should be given special consideration. The planning may need to be revised once the development or maintenance staff is identified in order to integrate the measures into their processes. A result of these planning tasks is the creation of a Measurement Plan for the program.

When considering which measures to use, the attributes described in this section should be weighted in context with the project's objectives, constraints, risks, and issues. The measures chosen must provide insight into the identified objectives, constraints, risks, and

issues. As these change, the measures in use need to be re-evaluated for adequacy in providing the necessary insight and changed, if necessary. The measure remains active only if it has a valid, justifiable purpose. Most projects can't afford to collect data and analyze measures that will never be used. Therefore, the selection (or re-selection) of measures is an iterative activity that occurs throughout the life of the project.

#### ***3.1.1.1 Attributes of Measures***

What are some of the characteristics of measures of which one should be aware? How does one know if a measure has these characteristics? The following list provides a description of the attributes of good measures as well as questions to ask to determine if a measure has that particular attribute.

- Relevance. “Why do I want to collect this measure? If I have more than one reason for having this measure, is there ambiguity in what it is trying to accomplish?” Only select measures that do not have numerous interpretations and that are pertinent to an end result you are trying to obtain.
- Completeness. “Have I covered all the bases? Have I left out a key parameter that is needed to analyze my results? Is there a need to weight one parameter more than another?” Be sure you identify a balanced set of measures and that your emphasis does not become skewed.
- Timeliness. “Did I find out what I needed to know in time to make a difference?” Be sure collection and analysis will provide the needed information in time to allow corrective action to be initiated.
- Simplicity. “Can I collect and analyze the data easily and cost effectively? Can the users/managers understand what it means?” Keep it as simple and logical as possible. The measures should be easy to collect, analyze, and understand.
- Cost Effectiveness. “Can I afford it? Can I *not* afford it? Does it provide more value than it costs?” Use data that is economical to collect. Use organizational or customer required data to address other program issues, where applicable. Leverage data collected for current management practices.
- Repeatability. “Will the same conditions provide the same answer twice? Is the accuracy and precision adequate?” This is important for comparing measures across projects.
- Accuracy. “Is my data really relevant to my purpose? Are my measures reliable? Am I measuring at the appropriate time?” Make sure that your measures are accurate and the resulting analysis accurately serves the intended purpose of the measure.

#### ***3.1.1.2 Identification of Project Issues (Objectives, Risks, Concerns, and Constraints)***

Issue identification and prioritization is the first activity in measurement process. Project issues and objectives, which vary from project to project, drive the measurement requirements. Thus, there is no “one size fits all” set of measures. As a starting point, the project management team and stakeholders identify the issues specific to their project and prioritize them.

As a minimum, the following should be inputs to the issue identification task:

- Project risk analysis
- Project constraints and assumptions



- Product acceptance criteria
- Known project problems
- Project goals and objectives
- External requirements or dependencies

The result of this task is a prioritized list of project specific issues, sometimes called the Project Issues Report (PIR). The prioritization scheme used is up to the discretion of the project management team and applicable stakeholders and is usually the same as or similar to the scheme used for risk prioritization for the project.

### ***3.1.1.3 Selecting the Measures***

There are many methods that can be used to select measures for a project. Two proven methods are provided in the following sections.

#### **3.1.1.3.1 Practical Software/Systems Measurement (PSM) Method**

Practical Software Measurement (and the evolving JLC/INCOSE Practical Systems Measurement) guidance includes a set of common program issues (systems issues listed below which vary slightly from PSM guidebook) that affect most projects. Specific project domains may include other issues not considered “common”. The common project issues are as follows:

- Schedule and Progress
- Resources and Cost
- System Performance
- Growth and Stability
- Product Quality
- Life Cycle Process
- Technology Effectiveness and Adequacy
- Customer/User Satisfaction

An organization may find one or more additional “common issues” that apply for all projects in their business domain. Also, relevant issues that require insight will change as the project progresses. These “common issues” are used as mechanisms to help identify project specific issues and then map them to measurement categories and appropriate candidate measures for the issue. The mechanism descriptions and mapping of these mechanisms are documented in the PSM Guidebook (see references). This process includes:

- Identification of candidate measures. For systems, the candidate measures may include some of those documented in the PSM guidebook for software, where they pertain to project management attributes rather than product attributes. Other sources of candidate measures include the INCOSE Guidebook, various standards, and texts (see references). In the near future, the Practical Systems Measurement Guidebook, which is a collaborative project between INCOSE and PSM, will also contain candidate measures for engineering a system.

- Establishment of selection criteria. Key items in the selected criteria include the measurement effectiveness to provide the desired insight into the issue, the applicability of the measure to the project's domain, the compatibility of the measure to the current management practices, the cost and availability of data to support the measure, the applicability of the measure to the particular life cycle phases, and how it addresses any external measurement requirements. (See PSM, section 2.3.2 for guidance on selection criteria.)
- Evaluation of candidate measures against the selection criteria to select the “best” measures (See PSM, section 2.3.2.)

#### **3.1.1.3.2 GQM Method**

Another example of a method that can be used to identify appropriate and useful measures from identified project goals is the Goal/Question/Metric (GQM) approach. The four basic steps of GQM are:

1. State the information Goal. Identify the information consumer groups (stakeholders) want to know and determine what they want to do with the information. Work top-down, including both organizational and project goals as appropriate.
2. Ask the Question. What questions should be asked to determine whether the goal is being met?
3. Determine the Measure. Identify the specific parameters that must be measured to answer the question(s) posed in Step 2. What measures are needed (directly or indirectly) and what must be measured (collected) to obtain it?
4. Do and evaluate. Apply the measures selected and evaluate their usefulness. Return to Step 1 or 2, if measures are inadequate for their intended purpose.

#### **3.1.1.4 Specification of the Measures**

After the measures are selected, it is important to specify them in an unambiguous manner. The measurement specification serves as the common set of instructions for obtaining, evaluating, and correctly interpreting the measurement data for a specific measure. Thus, it needs to mean the same thing to each practitioner. The specification should include:

- A clear definition of the measure
- Data types
- Data collection frequency (on a periodic basis, not event driven basis; usually monthly)
- Data preparation required
- Level and scope of measurement (At what level is data collected? What activities is it collected from?)
- Applicable phases for the measure and data collection
- Interpretation notes

The result of this task is a set of measures which directly address the program issues, are clearly defined and documented in specifications of measures, and serve as a basis for integration into the development or maintenance process.

### 3.1.2 Data Collection Method



A clearly defined and repeatable process needs to be created to describe the method by which the data will be collected. This method must identify the point(s) in time when the data will be collected, what (if any) tools will be used to accomplish collection, the people responsible for collecting the data, how the data will be validated, and what is done with the data once it is collected (storage and preparation). A simple example of a data collection method could be that on the first day of every month, a project member will be responsible for manually totaling the number of defects found in a particular product by any customer since the beginning of the previous month.

The measurement analysis results that will be performed following the data collection can only be as good as the data that goes into the analysis. Therefore, it is important to validate and verify the data that is collected. To help ensure that data collected is valid, the following should be attributes of the data collection activities, with someone given responsibility to ensure the action:

- All contractors and subcontractors should participate in the data collection
- Delivered data is periodically audited for quality, regardless of whether the data is delivered from an internal or external source
- Determination of data / measure combinations, comparisons, and other analysis needed is communicated to all responsible parties (including developers or maintainers)
- Data collected is demonstrated to be valid by the collecting party and is verified for adequacy

### 3.1.3 Calculation Method: Getting from Measures to Indicators



In some instances, a raw measure is the indicator. In most cases, however, the indicator is a mathematical combination of measures, and the method of calculating that measure or indicator needs to be defined and documented. Most indicators compare the relationship of two variables and can be communicated graphically. For each issue, there should be calculation of both current indicators (assessing the current situation), such as performance with respect to control limits and conformance to plan (variances of actual versus plan), and leading indicators (predicting the future situation), such as issues that may become problems, questionable trends, and feasibility of current plans.

It is often necessary to normalize the data using defined conversion rules or models to support meaningful comparisons between different project, process, or product attributes. These rules and models must be carefully validated with historical data. The measures and indicators then need to be aggregated (combining raw data and lower level measures into higher level summarizations) to a level adequate for the decision maker's needs. Aggregating the data requires defining relationships among the objects that are measured.

Where feasible, the calculation should be automated through supporting technology. Total **number of defects/time** is an example of a formula definition of an indicator. The data collected is the **number of defects** and the **time** period during which the defects were detected.

### 3.1.4 Analysis of the Measures or Indicators: Measurement Interpretation



To optimize program and system performance, careful tradeoffs must be made among cost, schedule, quality, and functionality. Appropriate measures and indicators (metrics) are essential inputs to this tradeoff analysis. Periodic analysis of the relationships between measurement results and the program requirements and attributes provides insight that helps identify problems early, when they are relatively inexpensive to resolve. The stored historic measurement data, together with program attribute data, form the basis for predictive models that should be used to estimate cost, schedule, and quality elements of the project or product. These estimates are essential for realistic and justifiable planning, change impact assessment, and tradeoff decisions.

Issue analysis is a systematic analysis process in which indicators are analyzed with qualitative program data to assess program status and risks relative to known issues. The issue analysis includes feasibility analysis to determine whether the plans and targets are achievable and project performance analysis to determine whether those plans and targets are being met. The indicators and performance characteristics are examined for critical path items or inconsistent trends that may be potential problems. The results of this analysis are then used to determine potential corrective actions and to identify new issues.

Within the analysis activities, variances and trends in data are the key to identifying dependencies among measures, as well as departures from planned values of the measures. These can show where improvements to processes, progress, or products could be made. Variances, which are a comparison between planned values and actual measured values, quickly indicate a momentary departure from the plan that may warrant investigation to prevent further digression. However, to understand a trend, and there may be a need to analyze more than two variables at one time. Specific analysis techniques that are identified and used should be documented. Any process, progress, or product changes made due to a perceived relationship between measures should be reflected in the analysis

of future data. This consistent use of analysis produces more predictable results. The analysis results should always be validated prior to preparing a presentation of the results.

#### **3.1.4.1 Goals/Control Limits for Each Measure**

Once a trend in the measurement data has been identified, even if the trend is such that the value of the measure is unpredictable (i.e., processes or quality of products are not under control), there may be a desire to improve that trend. Improvement is a result of change, and this change can be measured. The kind of change desired is defined by the planned or target value of the measure. If the value of the measure has no consistency over time, as is usually the case when the processes or quality of the products are not under control, then there may be a chosen range of values that are considered to be acceptable or desirable for that measure. Over time, as process improvement actions bring the processes and quality come under control, this range of values may be shortened to reflect more stringent acceptable or desirable values for that measure. This range of values, called the tolerance band, is defined by upper and lower control limits. If the measure has a predictable value, then there may be a value of the measure that is defined to be the MOST acceptable or desirable. This value then becomes the goal of the measure, and changes made are focused on driving consistent values of the measure closer to the goal. Setting goals and control limits for measures or indicators is intrinsic to controlled improvement.

### **3.1.5 Reporting and Using the Results**



The results of measurement analysis must feed back into the measurement process. Part of the measurement program documentation needs to describe how results will be used. The use of the results is the most important step of the process. Improvement of the project, process, or product as a result of measurement can only be realized through appropriate follow-up actions. For example, results can be used to orient decisions to the best alternative or to obtain understanding of causal relationships which, in turn, facilitate corrective actions to be initiated. (For more information on use of measurement, see section 4, Purposes of Measurement, and section 5, Application Guidance and Lessons Learned.)

## **3.2 Measurement Program Supporting Infrastructure**

An environment must be established that is built on management commitment to the objectives of the measurement program. These objectives must be clearly communicated to all stakeholders. Understanding the meaning of the selected measures and indicators and how measurement is going to be implemented and used will help ensure the acceptance and success of the program. Adequate resources must be allocated to performing the measurement activities from the selection of measures to the taking of actions. Appropriate planning, training and tools are other necessary components of the infrastructure. The key to successful acceptance, support, and effective use of the

measurement program is a good blend of effective planning and open, honest communication.

### **3.2.1 Management Commitment**

A critical aspect of the infrastructure of a measurement program is the level of support that is provided by management. Management's commitment to the objectives of the measurement program must be both visible and well communicated. Without this visible and continuing support, the infrastructure of the program will not be properly prepared nor sustained, and the likelihood of success of the program dwindles. In addition, management needs to provide ongoing feedback to the practitioners in the measurement program. The practitioners need to know that the data collected, the analysis performed, and the recommendations provided were useful and led to beneficial insight that influenced management's decisions. This communication has a valuable intrinsic benefit.

### **3.2.2 Measurement Plan**

The measurement plan is the documented result of management's objectives, and the process activities for identification of issues, selecting appropriate measures, and specifying those measures. The plan should be used to guide the implementation and execution of the measurement program. Also, it should be a living document that is updated whenever issues and associated measures change. The following is a list of typical contents of a measurement plan.

- Issues and Measures selected
- Identification and definition of data elements to be collected (as negotiated)
- Data Collection Details
  - ⇒ Data sources
  - ⇒ Level of measurement
  - ⇒ Units of measure
  - ⇒ Method of collection
  - ⇒ Frequency
- Data Delivery Details
  - ⇒ Aggregation structure
  - ⇒ Frequency of delivery
  - ⇒ Method/format of delivery
- Communication process and POC interfaces
- Analysis and reporting details and guidance
  - ⇒ Type of general analysis
  - ⇒ Frequency of analysis and reporting
  - ⇒ Criteria for additional or specialized analysis

### 3.2.3 Resources

As with any set of tasks, the measurement program requires careful planning, implementation, and control. All tasks should be identified, scheduled, and have effort and resource estimations performed. For new measurement programs, this planning includes the tasks associated with the initial implementation of the measurement program. Careful consideration needs to be given to the scope of the measurement tasks, the support required across the entire life cycle, and the assignment of the measurement responsibilities within the organization.

### 3.2.4 Training

The appropriate level of training must be planned for and provided to all stakeholders of the measurement process. All stakeholders need to understand the purpose of the measurement program and measures selected. In addition, the following is a list of the typical measurement roles and applicable tasks for which training may be necessary:

<b><u>TASKS</u></b>	<b><u>ROLES</u></b>			
	<b>Data Collectors</b>	<b>Measurement Analysts</b>	<b>Decision Makers</b>	<b>Process Owners</b>
<b>Issue Identification</b>		<b>X</b>	<b>X</b>	<b>X</b>
<b>Selection of Measures</b>		<b>X</b>	<b>X</b>	<b>X</b>
<b>Specification of Measures</b>		<b>X</b>		
<b>Measurement Planning</b>		<b>X</b>		<b>X</b>
<b>Data Collection Methods</b>	<b>X</b>			<b>X</b>
<b>Data Collection/Storage Tools</b>	<b>X</b>	<b>X</b>		
<b>Data Validation &amp; Verification</b>	<b>X</b>	<b>X</b>		<b>X</b>
<b>Data Preparation (Normalization, Aggregation, etc.)</b>		<b>X</b>		
<b>Analysis/Statistical Methods/Tools</b>		<b>X</b>		
<b>Measurement Interpretation</b>		<b>X</b>	<b>X</b>	<b>X</b>
<b>Reporting Techniques/Tools</b>		<b>X</b>		
<b>Decision Support Techniques/Tools</b>		<b>X</b>		
<b>Usage of Results</b>			<b>X</b>	<b>X</b>
<b>Feedback to Practitioners</b>			<b>X</b>	

### 3.2.5 Tools

Automate, automate, automate! This is a common mantra of many experienced measurement practitioners. Very few successful measurement programs exist that do not have tools that automatically support some portion of the data collection, analysis, and reporting. These tools can often reduce the effort needed to support a measurement program, as well as the potential for biased data. Depending on the tools chosen, support for data preparation, such as normalization, or analysis capabilities, such as linear regression, could also be available. Some practitioners even employ decision support tools to aid the evaluation of alternatives in order to provide management with the best recommendation or corrective action.

There is a risk of automating too much of the program, though. Do not automate for the sake of automation! Remember that tools have costs for procurement, support, training, and labor. Ask the following two questions:

- “Will incorporating and maintaining this tool require more effort than doing the work manually?”
- “Will the licensing and maintenance costs of the tool outweigh any savings in labor?”

If the answer to either of these is “yes”, then the process should remain a manual one, unless there it is expected that there will be a significant improvement in accuracy or usability of the data and results. In general, use of tools will reduce the labor and improve the effectiveness of the measure program, leading to a higher probability of success.

### **3.2.6 Measurement Data Repository**

Data storage and retrieval must be planned and adequately supported. The storage and retrieval mechanism may be either an automated database management system or via a manual repository of records. In either case, thought should be given to the organization of the repository and to the interaction of the data repository with any other data management tools. Without proper planning and ongoing support, the data can become unreliable, difficult to obtain in a timely manner, and more labor intensive to use.



## **4. Purposes of Measurement**

Each organization's processes and products are unique; therefore, any measurement program implemented for a particular process or product must be tailored to that organization. However, some general purposes and guidelines for measurement performance and usage are shared by experienced measurement practitioners pertaining to typical purposes and uses of measurement.

### **4.1 Defining and Communicating the Purpose of Measures**

The purpose of a measure is to provide meaningful information regarding the quality, adequacy, and/or progress of process, project, and/or products. Measurement does not in itself result in improvement. However, measures offer the insight needed for planning, controlling, managing, and improving:

- Product technical adequacy and performance,
- Schedule and progress,
- Resources and cost,
- Growth and stability,
- Product quality,
- Life cycle process performance,
- Technology effectiveness, and/or
- Customer satisfaction.

The objective of measurement is to obtain insight into issues that impact project cost, schedule, and technical (performance, functionality, and quality) objectives in order to enable the program decision makers to make informed decisions. Applied systematically throughout the project, measurement helps to:

- Identify specific problems
- Assess the impacts of these problems with respect to all program control factors (cost, schedule, quality, functionality, and performance)
- Determine feasible alternative solutions
- Perform tradeoff analysis and select the optimal approach (for all tasks and corrective actions)
- Provide accountability of decisions
- Communicate progress, performance, and problems in a more precise, standard, objective manner throughout the organization

When the purpose of a measure is clearly defined, the chances of achieving that purpose are greatly improved. In selecting measures of interest, it is valuable to consider the effectiveness of the measure in achieving multiple purposes, including:

- Assessing progress in meeting performance objectives
- Identifying opportunities to improve process and product and evaluating improvement results

- Developing projections and plans with greater confidence
- Providing feedback on status and progress
- Enabling quantitative process management

Regardless of the defined purpose of the measures, the implementation and execution of the measurement program must be done in a manner that builds trust and support throughout the organization. Doubts can arise concerning the legitimacy of the measures or the value added to the process or product that is being measured and analyzed. There is often resistance to the “scrutiny” of measurement, even when the true intention is a beneficial one such as identifying ways to improve processes or products. Clearly defining the measures’ purpose will help reduce the resistance and the potential for human bias (often unintentional) from creeping into the data, and therefore, adding credibility to the “objective insight” purpose of measurement. Involving stakeholders in the process from the beginning will also improve trust and buy-in. Achieving acceptance for a measurement program in an organization requires these plans and benefits be propagated to both those individuals who are involved in the measurement activity, as well as to those who are the recipients of measurement analysis results.

### **4.1.1 Characterization: Gain Understanding of Products and Processes**

#### ***4.1.1.1 Measuring Technical Performance***

Technical Performance Measures (TPMs) are critical technical parameters that a project monitors to ensure that the technical objectives of a product/project will be realized. Typically, TPMs have planned values at defined time increments, against which the estimated and actual values are plotted. Collection of TPMs allows trend detection and correction, and supports risk identification and assessment, thereby providing feedback information to identify potential performance problems prior to incurring significant cost or schedule impacts. In the engineering of a system, TPMs are a very common form of product measurement that also provides insight into project accomplishment towards the technical goals.

TPMs are selected by identifying the elements of the system for which performance is critical. Review of the systems engineering documentation and requirements specifications help identify these elements and the necessary planned values. However, the number of TPMs selected at the system level must be kept small to be cost-effective, since each system level TPM may be supported by several lower level, more detailed parameters. Thus, only the most critical parameters should be selected and the following criteria should be considered in the selection process:

- The parameter is one of the best indicators of the total system performance
- The parameter is directly measurable and easy to analyze and interpret
- The parameter can be defined with relatively meaningful tolerance bands

TPMs can be related to any functional aspect of the system; software, hardware, operations, or logistics. (See the DSMC SEMG reference for more TPM information.)

An example of a TPM is the *weight* of the end-product, such as an aircraft, where the product must be delivered weighing less than a certain amount. Throughout the project, as components are selected and integrated, the overall weight is calculated and monitored.

#### ***4.1.1.2 Measuring Process Performance***

Process measurement is critical in the determination of process efficiency and effectiveness. With most organizations trying to do more with less resources, there has been considerable focus in recent years on process improvement. Most of the process improvement frameworks, such as the various capability models, require some level of process measurement at each level above the model's initial level.

Process performance measurement starts with identifying the measurable attributes of the process. These should then be assessed against organizational objectives to select the attributes that will be measured. Periodic measurement of these attributes are the basis of *characterizing* the organization's performance of that process. The data can be tracked against the business objectives to *evaluate* the performance and used to identify those attributes of the process that are the highest priority to *improve*. (See SEI MPM reference for more information.)

### **4.1.2 Improvement: Identifying and Evaluating Process and Product Improvement Opportunities**

Measures are analyzed and combined to form indicators that provide the insight needed to identify opportunities for improvement. Opportunities for improvement are identified by analyzing actual measured process, product, or project attributes against target values and business objectives. Where variances exist are potential areas for improvement opportunities. These are then evaluated and prioritized based on the severity of the variance and the importance of the objectives. When improvements are made, measures are essential to discerning if the improvement activity has a favorable outcome. Although anecdotal information can indicate that a process or product has improved, only measures can *quantify* the improvement. Of course, the measurement information must be recorded in the same manner for both the initial and end states. As an example, a measure such as specification defects can be monitored in an effort to improve the specification development process and provide evidence that the improvement action was successful.

#### ***4.1.2.1 Enabling Quantitative Process Management (QPM)***

The purpose of QPM is to control the process performance of a project quantitatively. QPM, a key element of process maturity and assessment models, such as the INCOSE Systems Engineering Capability Assessment Model (SECAM), involves establishing goals for performance of processes, collecting and analyzing the measures of process performance, and making adjustments to maintain process performance within acceptable limits. This goal is more extensive than simple process improvement; it requires every player in an organization to be involved in not only the collection and analysis of measures, but also in the use of measures to aid identification and monitoring improvement opportunities in every element of the performance of business processes.

### 4.1.3 Prediction: Facilitating Projections and Planning

Projections and planning are improved by the availability of historical data. The data is used to formulate statistical and causal models for predictions. New projects can be budgeted, scheduled, and planned much more effectively if measures which provide historical data on previous similar projects/products are used. Organizations begin by compiling a database of information. As more data is collected, better baselines and control limits are established. Periodically, estimation models should be calibrated against this historical data.

### 4.1.4 Evaluation: Providing Feedback and Status

Measures can provide valuable feedback to the team or customer. A measure such as *customer satisfaction*, typically measured using a survey, provides feedback on the overall satisfaction with a product or service. A *product penetration* measure provides feedback on how well the organization has done in penetrating a given market. *Team effectiveness* measures based on surveys provide feedback to the team on how effective the individual members perceive the team to be.

Measures are an effective status reporting tool as well, particularly when presented in graphical form. An example of such a measure might be on-time deliveries or requirements verification completeness. The purpose is to provide the team with quantified information related to process, project, and or product, particularly in terms of status, progress, completion, and potential problems. Keep in mind, however, that during the early stages of a new measurement program, the measures themselves can be very volatile. In this event, careful consideration and qualification of measurement results may be warranted.

Measurement-based feedback improves the effectiveness of the project team in such ways as:

- Analyzing trends that help focus on problem areas at the earliest point in time,
- Providing early insight into error prone products that can then be corrected at the lowest cost,
- Avoiding or minimizing cost overruns and schedule slips by detecting them early enough in the project to implement corrective actions,
- Identifying complexities in the design or technical performance progress to enable a focus on risk areas, and
- Making adjustments to resources based on discrepancies between planned and actual progress.

## **5. Application Guidance and Lessons Learned**

For those embarking for the first time into the world of measurement, and perhaps beginning to plan a measurement program, there are some factors about measurement and lessons learned that are helpful to know. A description of the right and wrong ways to use measurement, some helpful hints about creating or maintaining a good measurement program, and some considerations of the influence that human factors can have on measurement programs are provided here for your assistance.

### **5.1 Contrasting Correct and Incorrect Uses of Measurement**

Measures that are used correctly will promote understanding and motivate action. But what happens if a measure is used incorrectly? What is the right or wrong way to use measures? This section answers those questions by listing the effects of using measures both in a constructive way and in a destructive way.

A measure used correctly:

- Is accepted as having value to the customer or as an attribute essential to customer satisfaction. The measurement customers can be people internal or external to the organization, the stakeholders of the measurement program, or even the users of the measure.
- Tells how well organizational goals and objectives are being met through processes and tasks.
- Stands the test of time. A measure that is used continually and is an accepted part of an organization's processes is most likely one that is being beneficial to that organization.
- Is the basis of indicators that provide insight that drives appropriate action.

However, measures are not always used appropriately. How do you know if a measure is being abused? You can recognize an incorrectly used measure if it:

- Is a chart or display tool (these may be used to present the results of a measure, but the measure does not consist solely of them).
- Is interpreted as team or personnel control tools. When the measure is purposefully used in this way, a natural result will be people feeling distrustful, and "gaming" of the system will occur.
- Lasts forever. Not all measures are appropriate to all phases of the lifecycle. There is no "perfect" measure; measures need to adapt to products and processes as they evolve.
- Is a scheduling tool. However, schedules (i.e., plans) form the basis of some good measures.
- Is a count of activity. This data becomes useful only when transformed into knowledge that can lead to action.
- Is used as an absolute. A single measure by itself is rarely an absolute indicator of anything.
- Is used to compare people, departments, or other human factors.

## 5.2 Tips and Rules of Thumb

Although measurement cannot guarantee program success, it will provide insight to make better decisions. The objective is to obtain the best insight possible. To facilitate this, a set of lessons learned from successful measurement practitioners has been pulled together. This set of tips and rules of thumb for making measurement a more effective project management tool and increasing the measurement program's probability of success are as follows:

- Project issues (risks, concerns, constraints, and objectives) should drive the measures and indicators selected. Never perform measurement for measurement's sake or for purely "political" reasons. Constrain the measures to those measuring process, product, or project attributes that require additional insight.
- Make sure that any standard (core) set of measures is kept small (try not to exceed 6). This will allow for comparison across the organization and across projects without significantly impacting the use of measures for project specific insight. Additional measures should be based on project/product specific goals, objectives, issues, and risks.
- Assign a measurement process "owner."
- Measures and their analysis should be traceable to issues, decisions and corrective actions. This allows better evaluation of the usefulness of the measures and provides better project accountability.
- Re-evaluate your measurement program at regular intervals. Is it working? Is adjustment needed to the process or measures used?
- You cannot measure what is not defined. For process measures, ensure you have a process defined first.
- Historically, people resist the idea of being measured. Find a way to use measurement in a positive, team unifying role.
- Measurement should be an integral part of the program management process throughout the entire life cycle and used as part of the basis of decisions.
- The measurement process should be a planned and natural part of the technical processes. This will minimize the amount of effort needed to collect data. Where possible select measures that require data that is naturally available in the development process. A data collection method that can be tailored to become part of the routine work that must occur anyway has the best chance of not being labeled as an additional burden.
- Try to automate data collection and reporting as much as possible. This removes potential bias in the data and provides data in a regular, timely manner.
- Measurement results should be interpreted in the context of other sources of information. When measurement results are combined with other program data, better insight can be gained of actual problem existence and the root cause of the problems. This insight is needed to make effective decisions. The types of data that are combined are dependent on the purpose of the measurement.
- Estimation models should be calibrated with actual historic data.

When analyzing measurement data, keep these tips in mind:

- A tool introduced to “observe” processes and/or products will, by its very nature, influence the “output.” Be aware of the influence that introducing a measurement program is having to avoid misdiagnosing an improvement as being the result of process or product changes.
- There may be multiple factors affecting the results, confounding the analysis and the decision maker.
- Correlation between two variables does not imply that changing one causes a change in the other!
- Projecting a trend based on history is likely to provide incorrect interpretations if you do not understand all of the underlying factors. For example, say you identify a trend of having a low number of defects found per widget. You might be tempted to expect to continue to measure low numbers of defects. But if you are not in a test mode, then it would be expected that low numbers of defects would be found until a test mode is entered. A sudden jump in the number of defects found per widget would be unexpected unless the underlying factor of current mode of operation is taken into account when analyzing historical data.
- Scaling factors and weights can distort or hide information.

As with any good organizational initiative, a successful measurement program requires preplanning. This planning will improve management’s ability to obtain and comprehend the information yielded by the measurement results and assists making appropriate improvement changes. Encouraging management to define their goals and expectations for achievement will also increase their participation in the preplanning phases. As a minimum, the planning effort should include consideration and definition of the following:

- Project/process/product issues. The issues identified drive the aspects of the project, process, or product which are targeted to be measured and improved. Some examples include any organizational goals and objectives, process improvement objectives and evaluation criteria/guidelines, risks, concerns, and programmatic or technical constraints.
- Measures and their specifications. As a minimum, specification of the measures includes its definition, data collection required, and interpretation notes.
- Specification of data flow. This could include data sources, frequency of data collection, the method for collection, and, if required, the delivery method of the measurement results.
- Measurement aggregation structures (i.e., what level of summarization is needed to provide the appropriate insight for each level of decision).
- Frequency and type of analysis and reporting
- Lines of communication and interfaces (defining discrete channels for open and honest two-way communication).
- The roles and responsibilities of all involved parties. Some typical roles that are defined for measurement programs are the measurement analyst, the collector of the measures, and the customer of the measurement results, which can be the program management team, the end-product customer, and other decision makers.
- The awareness and cooperation of the organizational cultural changes that will be made. Possible ways to help people become aware of the changes that will occur are to support training, mentoring, open discussions, policies that minimize misuse of measurement, and the communication of the expected reactions to the changes.

### **5.3 Human Factors**

The cultural and organizational changes and implications which are not adequately anticipated often become the major obstacle in establishing a successful measurement program. For example, performance measures of a process will often provide information and insight that ultimately leads to a more effective and efficient process. This enhanced process may require less effort and reduced staff to perform the same function. Management should address the need to bely employees' anxiety of job loss, while still promoting the trustful environment of process introspection that is required for maintaining a viable measurement program. Without proper planning for and communications regarding these factors, data will be biased and the measurement program may be rendered ineffective.



## 6. List of References

Measurement as a topic is very broad in scope. There is a wealth of information about measurement in many different industries and organizational types. Since organizations may need information on more specialized topics in measurement after understanding the basics, this section of the Primer was created to address that need. The following list of resources are organized according to specialized topics in measurement. Each sub-topic includes a short synopsis of the information available in it. Many of the concepts introduced in other sections of the Primer overlap with concepts discussed in the list of sources below. However, because only generalities are described in this document, no source is quoted verbatim and no references to other sources are made in this Primer outside of this section. This list of sub-topics is not exhaustive; if good references exist that discuss a particular sub-topic that is not listed here, please follow the feedback instructions in section 8 to pass along that information.

### 6.1 Measurement References

For more detailed information on the topic of measurement, consult the following references. These sources provide a more comprehensive introduction to measurement.

- *Metrics Guidebook for Integrated Systems and Product Development*, INCOSE, July 1995.
- *Practical Software Measurement: A Guide to Objective Program Insight* [PSM], Joint Logistics Commanders, Joint Group on Systems Engineering, Version 2.1, March 1996. (The measurement process provided in this reference is an easy to follow process that can be applied to any type of measurement, not just software. However, the measures discussed are software project measures.)
- *Metrics Starter Kit*, Air Force Software Technology Support Center, February 1994.
- *Metrics Starter Kit*, AMI's Center for System and Software Engineering. (Southbank University, 103 Borough Rd., London, SE10AA, UK.)

### 6.2 Selection or Creation of a Metric

If a specific type of measure needs to be created, for example a customer satisfaction measure, then it is helpful either to have guidance on how to create it or to use one that already exists. This section includes sources that will guide you on how to create a specific type of measure.

- Moody, J., Chapman, W., Van Voorhees, F. and Bahill, A., *Metrics and Case Studies for Evaluating Engineering Designs*, Prentice-Hall, 1997. (This book provides detailed information, including case studies, on the use of design difficulty and resource measures.)
- Defense Systems Management College, *Systems Engineering Management Guide*, DSMC Press, Fourth Edition (Draft) [DSMC SEMG], 1996 (This guide has good information on the selection and use of Technical Performance Measures.)

- Kan, S., *Metrics and Models in Software Quality Engineering*, Addison-Wesley Publishing Company, 1995. (This book provides information on the selection and use of software quality measures.)
- Putnam, L. and Myers, W., *Measures for Excellence*, Prentice-Hall, 1992. (This book provides information on the selection and use of project performance and software quality measures. Much of the information applies equally to the systems environment.)
- Cruickshank, R., Gaffney, J. and Weling, R., "Measurement at the systems level: where we are and where we ought to be," *Proceedings of the 4th National Council on Systems Engineering*, August 1994. (This paper describes how the measurement process includes the selection of measures; the collection of data; and the integration, analysis, and reporting of quantitative information derived from the data.)
- Gause, D.D. and Weinberg, G.M., *Exploring Requirements: Quality Before Design*, Dorset House Publishing, 1989. (This book includes discussion on ambiguity measures and customer satisfaction measures.)
- Hoffman, K.C., "Management of enterprise-wide systems integration programs," *Proceedings of the Second International Conference on Systems Integration*, (Cat. No. 92TH0444-0), P. 4-13, IEEE Comput. Soc. Press, 1992. (This paper describes measures in system integration programs.)
- Kasser, J. and Schermerhorn, R., "Determining metrics for systems engineering," *Proceedings of the 4th National Council on Systems Engineering*, August 1994. (This paper suggests some product and progress measures.)
- Martin, J.N., "On the diversity of process metrics users: identification of metrics types and other attributes," *Proceedings of the 5th National Council on Systems Engineering*, July 1995. (This paper identifies specific types of measures.)
- Thomas, H.D., "On management and metrics," *Proceedings of the 3rd National Council on Systems Engineering*, July 1993. (This describes a Customer Satisfaction Metric.)
- Patterson, Marvin, and Sam Lightman, *Accelerating Innovation - Improving the Process of Product Development*, Van Nostrand Reinhold, New York, 1993. (Chapter 3 - Designing Metrics)

### 6.3 Starting a Measurement Program

Measurement is not useful without a defined process which outlines how and when to collect the data, how and when to analyze the data, etc. These sources give guidelines on how to create a measurement program that will support measurement.

- Grady, Robert B., *Practical Software Metrics for Project Management and Process Improvement*, Prentice-Hall, 1992.
- Hetzel, Bill, *Making Software Measurement Work: Building an Effective Measurement Program*, John Wiley & Sons, Inc., 1993.
- Grady, Robert B., Caswell, D.L., *Software Metrics: Establishing a Company-wide Program*, Prentice Hall, 1987.

- Fisher, G.H., “Startup guide for systems engineering metrics,” *Proceedings of the 3rd National Council on Systems Engineering*, July 1993.
- Rhodes, D. and Mastranadi, A., “Getting started with a measurement program,” *Proceedings of the 2nd National Council on Systems Engineering*, July 1992.
- Donnell, A. and Dellinger, M., *Analyzing Business Process Data: The Looking Glass*, AT&T Quality Steering Committee, AT&T, 1990.

#### **6.4 Improving an Existing Measure**

How effective is a measure? Is it measuring what it is intended to measure? These sources explain how to examine a measure and improve it.

- Ashburner, E.J., “The theory of testing applied to the development of a system engineering metric,” *Proceedings of the 4th National Council on Systems Engineering*, August 1994.
- Martin, J.N. and Miller, W.D., “Re-engineering of the metrics collection process,” *Proceedings of the 5th National Council on Systems Engineering*, July 1995.
- Miller, W. D., “Systems engineering metrics ++,” *Proceedings of the 4th National Council on Systems Engineering*, August 1994.
- Moller, K.H. and D.J. Paulish, *Software Metrics: A Practitioner’s Guide to Improved Product Development*, IEEE, 1993.

#### **6.5 Introduction to Statistics, SPC, and Process Improvement**

The following sources contain information on statistical concepts and their uses in management and business for process improvement and control.

- *Practical Software Measure: Measurement for Process Management and Improvement* [SEI MPM], Software Engineering Institute, Guidebook CMU/SEI-97-HB-003, April 1997.
- Wheeler, Donald J., *The Key to Managing Chaos and Understanding SPC*, SPC Press Inc., 1996.
- Pitt, H., *SPC for the Rest of Us: A Statistical Process Control*, ASQC Press, 1996.
- Keats and Montgomery, *Statistical Applications in Process Control*, Marcel Dekker, Inc., 1996.
- Dovich, R., *Quality Engineering Statistics*, ASQC Quality Press, 1992.
- Mandel and Laessig, *Statistics for Management*, Douglas Publishing Co., 1996.

## 7. Example Measures

In Section 2, three different types of measures were defined; Process, Product, and Progress. This section will illustrate a measure from each area and how they are used in the systems development process. The measures chosen for this section were selected as being representative of each of the types of measure. They are not necessarily advocated as the measure one should use for all organizations. As emphasized earlier, the measures selected should be based upon specified goals and objectives. Remember that in an actual application of these or any other measures, all applicable measures and program information that is available should be used to support making decisions. Use extreme caution if you decide on a course of action based upon a single measure in isolation!

The format that will be followed for each example will be the same as that employed in another Measurement Working Group Product called the Metrics Information Systems Tool (MIST), namely: the potential usage; the source of the measure; the appropriate user(s); how the data is collected and at what interval; the basic algorithm used in calculating the measure or indicator; and the interpretation of the results.

### 7.1 Example Process Measure: Review Rate

This measure is obtained from the Development Team and can be used by the management, the development team, and any individuals concerned with the quality of the review process. The number is usually calculated on a project basis but compared against the results from similar projects. This comparison might involve using statistical control charts to insure that adequate time is being spent in the review process.

This measure is obtained by dividing some measure of size for the project by the cumulative amount of time spent in preparing for the review. Size can be determined by such factors as: number of requirements, number of documentation pages, number of test items covered, or number of lines-of-code covered at the review. The important issue is to agree on one measure of size and then use it for all the projects so that valid comparisons can be drawn. This rate can be calculated for designated reviews during the development process and then compared against other projects' review rates from their equivalent stages in development. If a given project exceeds the statistical control limits, the development team needs to ask why. This rate can also be correlated with number of errors found.

Figure 2 is an example of a plot of this measure along with the corresponding statistical control limits that are derived from other projects' review rates at those same points in the development schedule. The X-axis represents the time at which the designated reviews occur, while the Y-axis is the review rate. The calculated review rate for the project of interest and the associated quality control limits are plotted on this graph. As can be seen from the graph, at the third major review, the review rate is higher than the control limits. This indicates that not enough time was spent in reviewing the material. Inadequate time

spent in the review process could result in system errors going undetected until later development phases. Defects found later in development are more costly to fix than are defects found earlier in development, and this measure may be one indicator of either an increase in cost to fix problems found late in development or a decrease in quality of the end product (for those defects that go completely undetected).

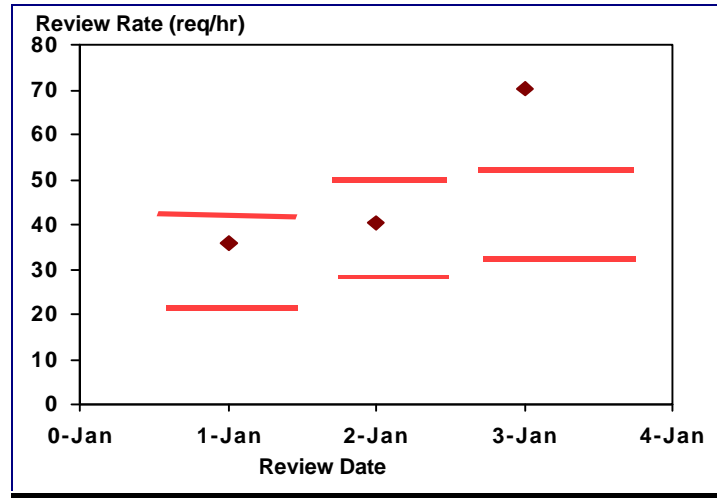


Figure 2: Plot of Review Rate

## 7.2 Example Product Measure: Defect Density

This measure reflects the weighted average number of major defects per normalized system engineering “size” of a given project within an organization. A “defect” might be defined as any deviation or omission from the system’s requirements; namely an error. By major defect we might mean one that would result in the system not being able to perform its mission and/or the operation of the system could result in potential loss of human life. Each organization would need to define its own “severity” classification and then decide upon which levels of that scheme constitute major errors. Normalized “size” can be measured as: number of requirements, number of Function Points, number of documentation pages, number of lines of computer code etc., normalized by an appropriate factor. The important factor is to determine a common measure of “size” within the organization for every product. The information needed to calculate Defect Density can be found in an organization’s problem reporting database and measurement database (or equivalent database that keeps the “size” of the project). The user of this measure would be the organization’s management, the various project team leaders and developers, and anyone else concerned with tracking the quality of the organization as it pertains to product quality. This measure would be reported on at least an annual basis to provide the overall organization’s quality trend. This measure could also be tracked per project and reported at each major milestone review.

For our example, suppose we consider “size” using the number of system requirements with a normalizing factor of 100. Suppose we have 3 projects with respective weightings assigned as .5, .25, and .25. Management feels that Project 1 (.5) is twice as important as

the other two. (Determining weights is a highly subjective judgment. If management does not specify the weights to employ, equal weighting can be used.) Suppose for the last four years that the value of this measure has been reported as 3.7, 3.4, 3.2, and 3.1. For this year the cumulative total number of requirements for each project was respectively 800, 700, and 300 respectively. Normalizing these values by 100 yields 8, 7, and 3. Suppose from the problem report database we find the cumulative number of major defects for each of these programs were: 16, 4, and 20 respectively. Then the value of this measure for this reporting period is the weighted sum of the normalized defects rate per 100 requirements:

$$\text{Defect Density} = (.5 (16/8) + .25(4/7) + .25(20/3)) = 2.8$$

The organization is therefore "averaging" across the three projects about 2-3 major defects in every 100 system requirements. If we plot this measure over time we can see how well the organization is doing in improving quality. This is illustrated in Figure 3.

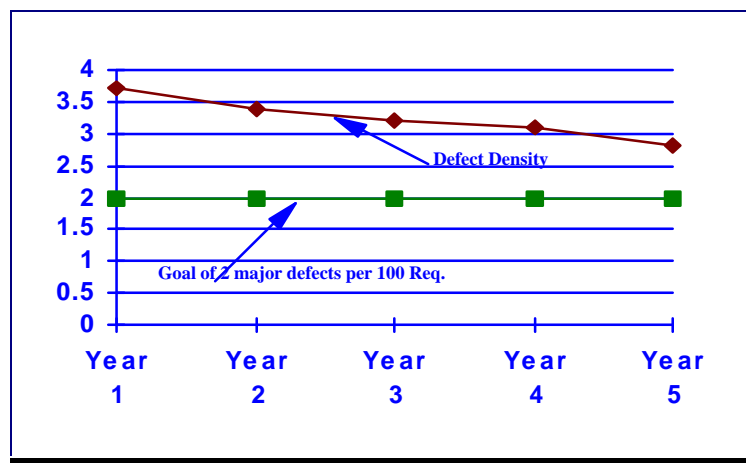


Figure 3: Defect Density Plotted Against Year

In the plot we see the organization's goal is 2 major defects for every 100 system requirements. The organization has shown steady progress to achieve that.

### 7.3 Example Progress Measure: Requirements Stability

This is a measure that reflects the number of requirements that have changed (e.g. added, modified, or deleted from the last baselining) divided by the current number of baselined requirements. The higher this number is the more unstable the requirements appear. Low values indicate stability. If the requirements are changing too fast, this introduces problems in all areas of the system development, especially in meeting schedule and keeping within budget. The data for this measure is obtained for a given baseline from a requirements baseline management database or equivalent. This measure can be reported weekly or monthly depending upon the needs of the organization and the nature of the project. This measure is of interest to project management and the system developers.

For an example of this measure suppose from the last baseline: 5 new requirements were added, 6 deleted, and 10 have been modified for a total of 21 changes. At the current baseline suppose there are 100 requirements. Thus the requirements stability measure is:

$$\text{Requirements Stability (present)} = 21/100 = .21.$$

Suppose for the past 6 baselines of the system, the values were 1, .6, .5, .3, .27. and .18 respectively. (Notice if we have a new system development the value of this measure is initially 1 since we have all new requirements.) Figure 4 shows a plot of this measure against the baseline version number with baseline 0 being the start of this new system. As we can see from this plot the requirement changes are slowing down indicating the number of changes is getting smaller. We see that we have achieved our goal of no more than 25 requirement changes per 100 requirements by baseline 5. Also we can get an idea of how fast we are achieving this stability by looking at the slope of this curve.

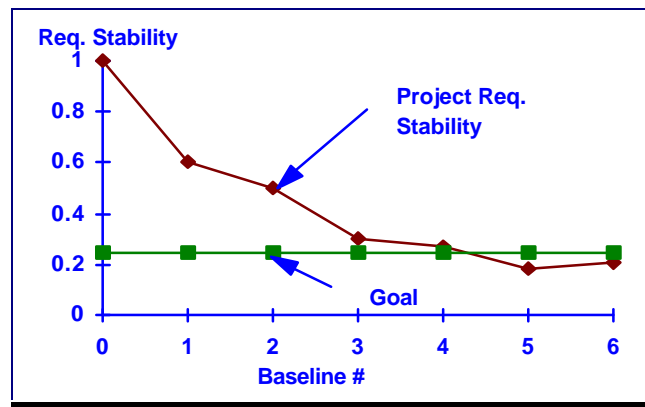


Figure 4: Plot of Requirements Stability Vs Baseline Number

The user of this measure would need to establish the acceptable ranges and rates of change. In addition the user needs to be aware of a possible ripple effect in that a few modifications to major requirements could affect many others, thereby inflating this measure.

The importance of this measure, as with any measure, is that it serves as an indicator or flag. Something has changed in the process. That change may be good, detrimental, or neutral to our system development. The key is to determine why the value of the measure has changed, make a determination of the impact, and then determine whether any action is required!

The reader is again reminded to use caution in drawing inferences in any of the above examples. One must look at a number of measures to get a total perspective of the system development before taking any action. Consider all available data relating to the problem both qualitative and quantitative.

## **8. Feedback Forms**

Any comments or suggestions that you would like to share on the form or content of this Primer are welcome. Please feel free to use the feedback forms provided in this section to communicate your thoughts. (If email is your preferred mode of communication, the appropriate email address to send your comments to is: [garry.j.roedler@lmco.com](mailto:garry.j.roedler@lmco.com)) These forms can either be faxed to: Garry Roedler (610) 531-1190 (USA), or mailed to the following address:

Garry Roedler  
Lockheed Martin Management and Data Systems  
PO Box 8048  
Building A, Room 13A30  
Philadelphia, PA 19101 USA

If you have any further questions, please call: Garry Roedler, (610) 531-7845.



## INCOSE MWG - Measurement Primer Feedback Form

Name: \_\_\_\_\_

Company: \_\_\_\_\_

Address: \_\_\_\_\_

---

Would you like responses to your comments (Y/N)? \_\_\_\_

[illegible]